TITLE: SOLIDS TRANSFER TEAM **- 2001**

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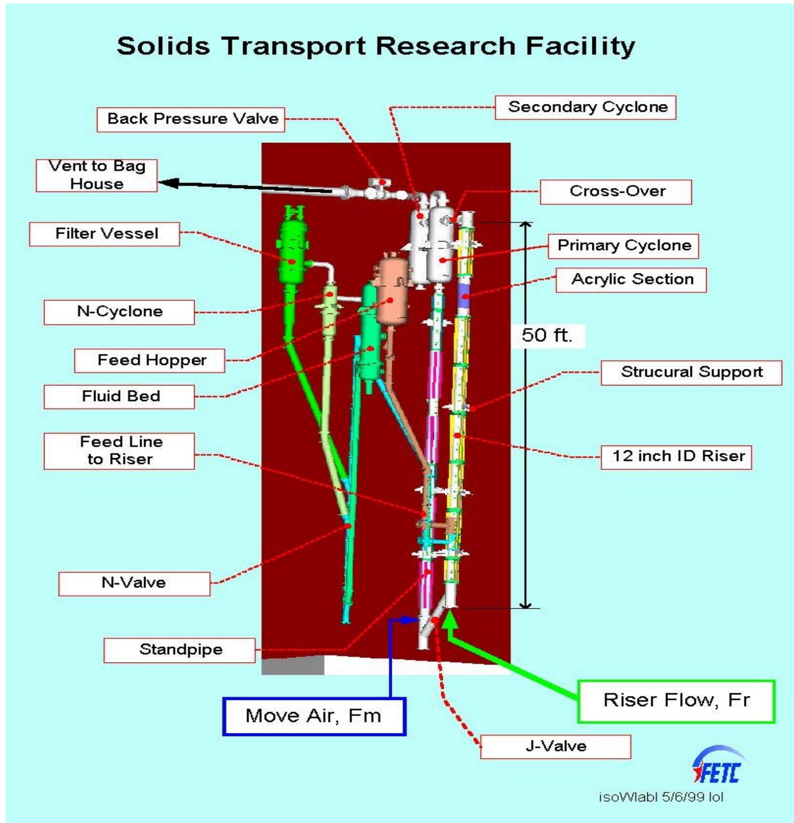
DESCRIPTION:



Cold Flow Circulating Fluid Bed Facility

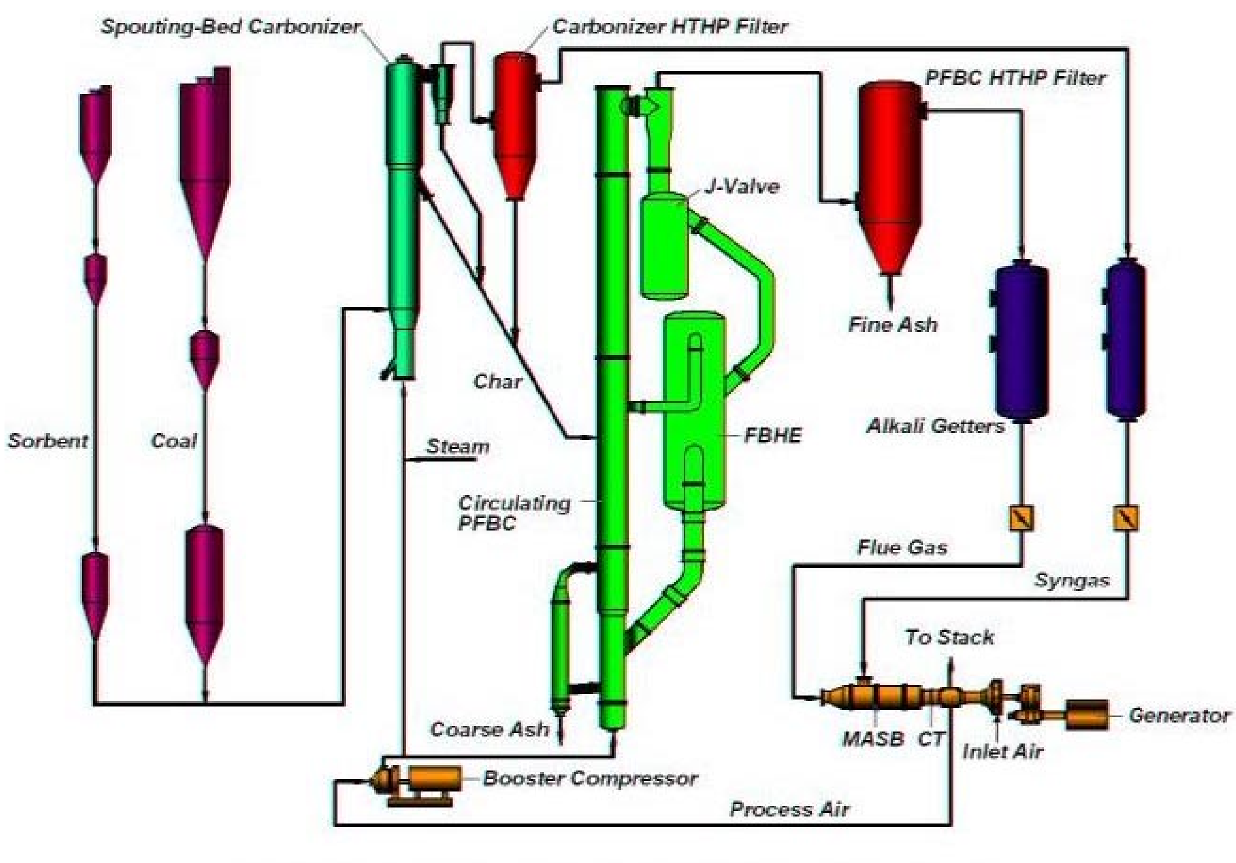
The research team's activities center on the operation of the Cold Flow Circulating Fluid Bed facility (CFCFB). The bulk of the research results were taken from study on the relatively large circulating-fluidized-bed unit within this facility. The main CFCFB riser is 1-foot in diameter and 50-feet tall and capable of operating at pressures up to 3 atmospheres. Operations were conducted with a coal-derived powder known as coke breeze, as well as various cork powders designed to simulate the performance of coal in a hot pressurized gasifier. The facility is instrumented with several unique advanced instruments in addition to the standard process instrumentation and flow controls. This instrumentation and operating methods have been developed and applied in order to gain a deeper understanding of the motion of solids within the Circulating Fluid Bed (CFB) loop.

RESEARCH OBJECTIVES:

Gas and solids flow within fluidized bed technologies is complex and often problematic. Our team conducted research to increase the knowledge base in this field of gas-solids hydrodynamics, particularly for coal conversion technologies such as coal combustion or gasification. Mixing patterns and solids residence times within the riser of a CFB are important to aid operations and design in developing technologies. Over FY 2001, the research studies included:

1). testing various non-mechanical valves for use in the char transfer system for Advanced Pressurized Fluid Bed Combustion systems (APFBC);2). developing and testing advanced control methods including Neural Networks and Kalman Filters for CFB reactors;
3). characterizing operating regimes for a CFB riser to improve empirical models, validate Computational Fluid Dynamic (CFD) models, and develop the Transport Gasifier;
4). measuring solids flow parameters such as shear to characterize solids in moving beds within the frictional flow regime to support development of CFD models in this flow regime; and
5). Evaluating the relationship between NOx and operating conditions for commercial Circulating Fluid Bed (CFB) boilers.

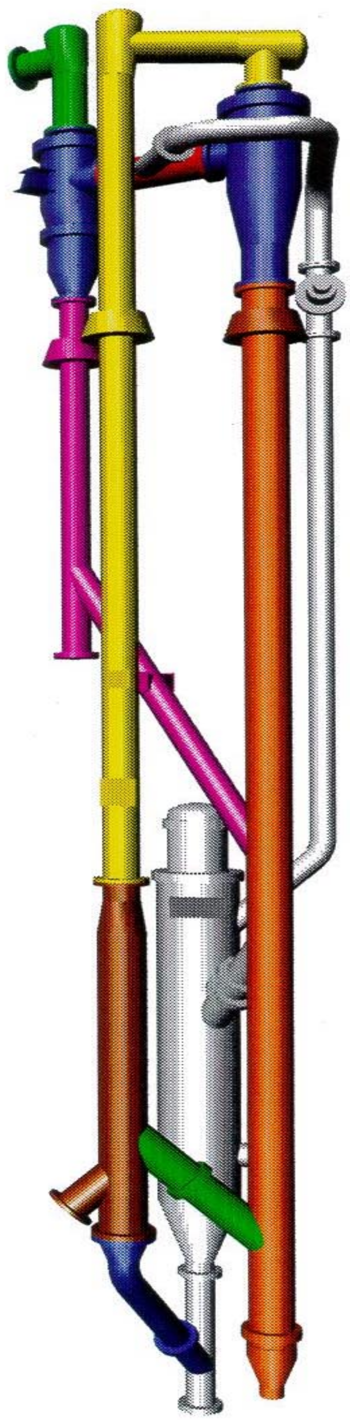
In our efforts to study these issues advanced instrumentation was identified, developed, and implemented in the CFCFB. Steady state, dynamic, and Computational Fluid Dynamic (CFD) models were developed, verified, updated, and enhanced.



Advanced Pressurized Fluid Bed Combustion system

LONG TERM GOALS/RELATIONSHIP TO NETL=s PRODUCT LINES:

The CFCFB is a unique facility with potentially many diverse applications, customers and opportunities to generate new business. Its potential is clear from the fact in its short lifetime it has had interest from three FE programs and numerous outside organizations. Product funding is provided from Gasification Technologies the to aid development of the Transport reactor.Combustion Systems funding support the evaluation of non-mechanical valves such as the N-valve to facilitate char transfer between carbonizer and combustor in advanced power systems. Advanced Research Power provides funding to develop advanced instrumentation, controls, and models to aid development of coal power systems. The CFCFB has the potential to become a world class facility in demand from a variety of customers. Providing the facility with the advanced instrumentation to allow quantitative characterization of the gas-solids flow behavior is critical to achieving this goal. The long-term goal of the team is to generate high quality detailed experimental data and validate computer models to aid process design and operations.
The Transport combustor, developed by KBR and tested at DOE's Power System Development Facility (PSDF), was demonstrated to achieve a thruput nearly twice that of any other combustor in the power industry. This offers the potential for reducing both capital-cost and cost of electricity - especially if the design expectations for gasification and hot gas cleanup can be demonstrated. The goal is to establish the feasibility of making specific design and/or operational changes to the Transport reactors at PSDF, the Transport Reactor

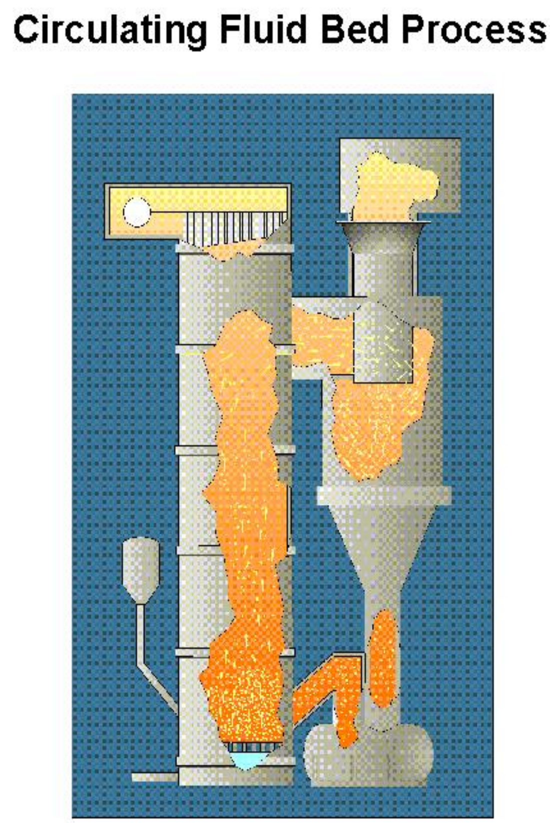


Artistic drawing of the Transport gasifier at the Power System Development Facility.

Developmental Unit (TRDU), the hot gas cleanup Pilot Development Unit (PDU), and the Pinon Pine (CCT) transport desulphuriser. The CFCFB project and associated instrumentation and modeling efforts address this goal.

The APFBC system developed by Foster Wheeler (FW) was built at the PSDF and was awarded a Clean Coal Technology (CCT) contract. One reason that the pilot plant at PSDF was not run was the critical solids transport issues. The carbonizer in FW's APFBC process produces a hot fuel char that must be transferred from the carbonizer into the combustor.

Several concerns exist about operating the N-valve built at PSDF including scenarios such as gas leaking from carbonizer to combustor due to a PCD back pulse, loss of fuel feed control, inability to put one cycle in standby while another is under being serviced, and the potential for segregation causing char feed difficulties.The cold flow unit will be used to evaluate the feasibility of achieving consistent stable operational requirements using a loop seal or an N-valve. The goal is to establish the feasibility of making specific design and/or operational changes to the APFBC process being operated at PSDF and design



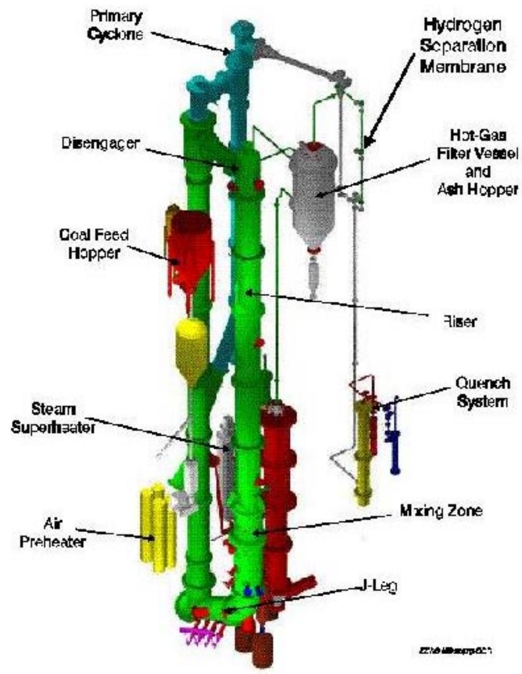
Commercial Circulating Fluid Bed (CFB) boiler

SUMMARY ACCOMPLISHMENTS:

Transport Reactor

Efforts to improve the Transport Gasifier varied from measuring particle-wall shear in the standpipe of the cold flow CFB to analyzing data from the Transport Reactor Development Unit (TRDU) being operated in Grand Forks North Dakota. Both efforts required development of computer models.

A steady state model, SS-CFB, was developed to compare test data from the TRDU with typical gasification kinetics. This model was developed into a JAVA-based code with user-friendly drop down menus, the capability to conduct a sensitivity study between variables of interest, and animations displaying ed for a CCT project.relative gas and solids velocities. The results of the SS-CFB verification with TRDU have been published in the AIChE Research Journal (Shadle et al., 2001) along with figures. This investigation demonstrated that the Transport reactor was successful in gasifying Powder River Basin subbituminous coal. Using the transport technology, this coal was found to exhibit reactivity 20 times greater than those previously recorded.



Transport Reactor Development Unit (TRDU)

Testing in the CFCFB with a coke powder, referred to as coke breeze (mean size of 250 µm), provided evidence of the highly integrated nature of the transport reactor technology. For instance, the total mass inventory was found to contribute to pressure oscillations or operational instabilities (Lawson and Shadle, 2000). Statistically designed tests over a period of weeks indicated that a systematic and undetermined error was creating poor repeatability in the CFB response. These tests were conducted with coke operated at high riser transport velocities. For example, duplicate test conditions resulted in 5 to 10% increase in the riser pressure over the period of 6 hours. Secondary effects were studied to explain this creeping performance.

Secondary variables were considered, in addition to the primary variables studied, such as the riser flow and solids circulation rate. The secondary variables tested were the inventory, fines concentration, hysteresis in solids flow, radial distribution of standpipe aeration, recycle of secondary cyclone solids, and variations in standpipe voidage. While inventory, recycle of solids from the secondary cyclone, and hysteresis demonstrated minor influence on riser performance, the presence of fines caused a dramatic increase in the solids circulation rate and in the riser pressure drop, ΔP. When the fines level was controlled, replicate tests conducted over a period of three months were demonstrated to be consistent and within several percent error.

Instruments required to determine these effects include the continuous measurement of solids flow rates using a spiral vane inserted into the standpipe (Ludlow et al., 2001). The effect that the standpipe void fraction has on circulation rate measurement is considered. A standpipe model was developed using the incremental pressures and the Ergun equation to estimate voidage profiles along the standpipe. Efforts continue to obtain real-time continuous measurement of the partially fluidized packed bed voidage using a densitometer. This instrument works on the principle of measuring the differences in capacitance for the gas and solids.

In addition, the flow of solids from the standpipe into the riser was proposed as the cause for hysteresis and, thus, for unreliable solids flow control algorithms. A force balance on the solids flowing down the standpipe was formulated. A wall shear vane instrument was developed to provide the missing data (Lawson et al., 2001). The wall shear provides a sensitive measure in a static bed of the minimum fluidization velocity, with the shear force decreasing as the gas velocity increases.

Likewise, the shear force varies inversely with gas pressure drop, solids circulation rate, and bed void fraction. Increasing factors like fines concentration, standpipe height, and bed inventory influence the measured shear. Further understanding of this behavior is important developing control methods to identifying their stable limits. Two methods of developing operations control algorithms have been explored: Neural Networks and Kalmann Filters. In addition a dynamic model (DYNCFB) is being developed to provide an ACSL code of a CFB compatible with the PCTRAX commercial plant simulator.

APFBC

In an APFBC application, the loopseal is used to provide a seal between the high-pressure, spouted fluid bed carbonizer and a lower pressure, circulating fluid bed combustor. The particle size distribution and density distribution from the carbonizer can be quite broad, which promotes segregation, and in turn, leads to a loss in solids' flow to the combustor. Other issues include the lack of storage capacity in the N-valve in the event of an interruption in the process, loss of seal upon back pulse of the candle filter system, and uneven flow of solids to the combustor. A project was undertaken at NETL to evaluate these issues in a cold flow model. The effort has continued with design and installation of a 6-inch diameter, 37-foot tall N-valve in the CFCFB facility. This configuration includes a fluid bed and the associated cyclone and particulate filter vessel. The system vessels and piping have been installed, and final hookup of instrumentation is on going. Shakedown tests are projected to begin in March 2001.

A 5-foot high and 10-inch ID Loopseal was operated under ambient conditions to evaluate segregation and seal integrity. Experiments within this loopseal were conducted with coke, cork, and sand in various size and density mixtures (Shadle et al., 2001). The effects of fluidizing air to the loopseal, mass circulation rate, and solids' mixture on segregation were also evaluated. Evidence of segregation was observed with both the density and size mixtures. This segregation, however, was found to be reversible by simply increasing the aeration rates in the loopseal riser to a flow that was above the minimum fluidization velocity of the top size for the most dense particles. Purge methods were evaluated and surge events were minimized using a gradual increase in aeration rates.

In addition, this loopseal configuration has the highest pressure at the top of the stand-leg and, as such, is inverted in its pressure profile compared to typical applications in CFB combustors. Thus, tests were conducted evaluating the potential for the loopseal to be blown out by the reverse pressure differential, particularly during standby operations when solids feed from the carbonizer is suspended. Standby operations in an inverted loopseal were tested by isolating the lower standpipe in the CFB from the rest of the loop using a butterfly valve and pressurizing the standpipe bed below this valve independent of the loopseal and riser operations (CFB schematic). The overall pressure differential across the loopseal was varied, causing a drop in the standpipe bed level, but leaving the inventory in the riser of the loopseal unaffected (histogram). Conditions were explored to maintain the solids' inventory as the pressure drop across the loopseal was changed. Fluidization rates exceeding 20 times the minimum fluidization velocity were found to result in only a slight and gradual drop in the loopseal's pressure seal.

Seasonal NO_x Variation in Commercial CFB boilers

A study was undertaken to understand the effect of season on ammonia usage to control NO_x in CFB coal waste-fired power plants (Ogunsola et al., 2001). Historical data on fuel properties, operating conditions, and emission characteristics provided by two plants were used. The data were examined and analyzed for any evidence of seasonal trend in NO_x emissions.

Relatively higher ammonia was required to control NO_x in winter than the rest of the year at the plant that uses it to control NO_x. A predictable seasonal variation was observed for only a few parameters (humidity ratio, ammonia consumption, fuel moisture content, and ambient air temperature). Bed temperature, excess oxygen, Ca/S ratio, Ca-sorbent particle size, and ammonia consumption were related to the variation in NO_x emission.
Consultations were also provided to operators from a second CFB waste-fired boiler. This plant had met its NO_x emission quota and was faced with plant shutdown until the end of the month. After discussing the mechanism of NO_x formation and destruction and the many parameters which can impact these processes, the plant operators were able to vary operations sufficiently to remain in service.

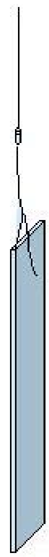
CFD Model Validation

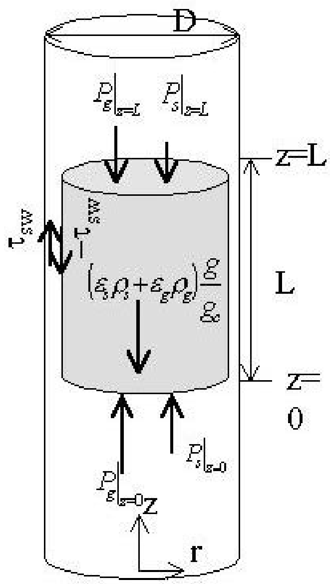
The initial focus for model validation has been to clearly define the boundaries between various riser flow regimes (Shadle et al., 2002). The cold flow CFB main riser was developed to be large enough to minimize wall effects, tall enough to achieve fully developed axial profiles, realistic, and yet simple. A novel method was developed to accurately determine the solids saturation carrying capacity for a given gas velocity (Monazam et al., 2001). This represents the boundary between the dilute homogeneous riser regime and the dense, particle fluid- compromising regimes. The dense riser operating regimes can lead to various dynamic operational instabilities or choking conditions. CFD simulations of risers must be able to differentiate these flow regimes. Thus accurate data and comparison with CFD models are sensitive validation tests.

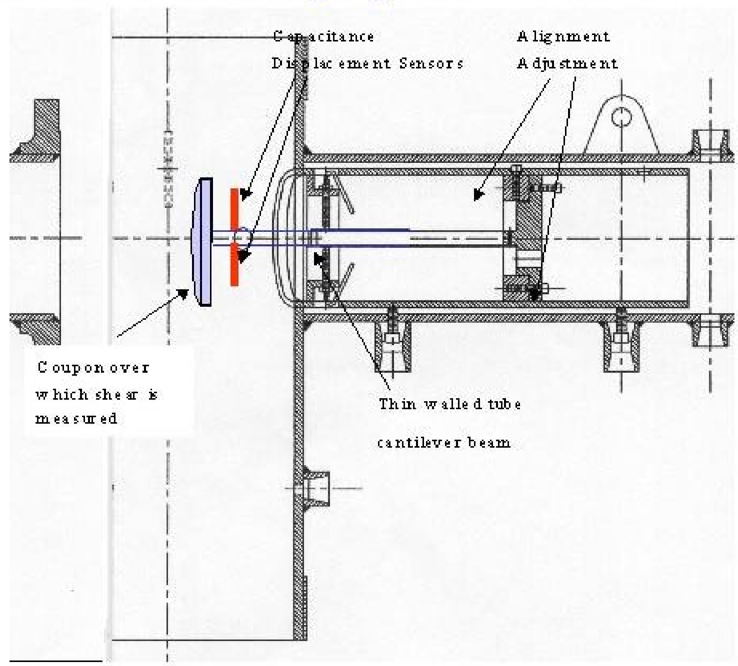
A CFD simulation of the cold flow CFB loop was generated using 2D and 3D Cartesian coordinates under the MFIX code. Even with geometric and operational simplifications, this simulation was computationally intensive and time-consuming. This is because of the shear scale of the unit being simulated and the grid scale necessary to obtain reasonably accurate results. These MFIX simulations exhibit significant particle clustering within this dense operating regime. Flow patterns show dramatic recirculation zones within the riser. However, quantitative comparison is lacking, with the simulation producing excessive circulation and unrealistic exit and entry effects. Guenther et al (2002) are developing more CFD simulations of CFBs. This report will help to define the required grid resolutions and numerical methods and compare pressure profiles with smaller scale literature data.

Advanced instrumentation is being developed to measure solids velocity and to map the solids density across the cold flow CFB riser. The solids velocity profile is accomplished using an optical probe. The data reduction algorithms have been developed and are being implemented and verified. A high-speed and high resolution capacitance imaging system (CIS) is being constructed to characterize the bed density across the riser. This instrumentation was previously demonstrated for bubbling fluidized bed regimes, but has not been used in CFB applications.

Analysis of Frictional Flow Regime using Shear Measurements in the Standpipe of CFB







$$\frac{\Delta P_s}{L} = -\rho_s \varepsilon_s g - \frac{4\tau_{sw}}{D} - \frac{\Delta P_g}{L}$$

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The “Spiral”

- Measures Solids Circulation Rate (lb/hr)
- Placed in Standpipe ~10 ft From Bottom
- Continuous Measurement
- Fast Response Time
- Support is Intrusive
- Measurement Depends on Local Bed Density

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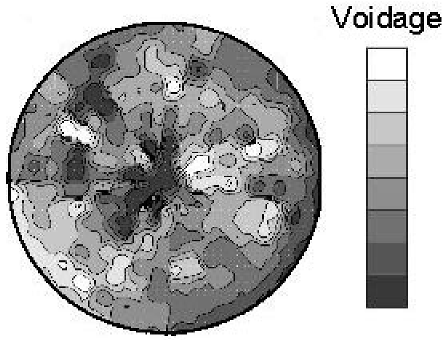
Capacitance Imaging & Voidage Measurement

Capacitance Imaging

- Real -Time Imaging of Riser Solids Radial Distribution
- Experimental Verification of MFIX



Voidage Measurement

- Real Time Standpipe Void Fraction Measurement
- Input to Real-Time Void Fraction Correction for Spiral

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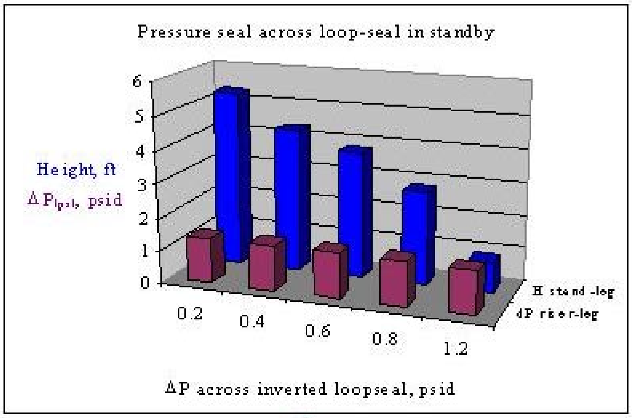
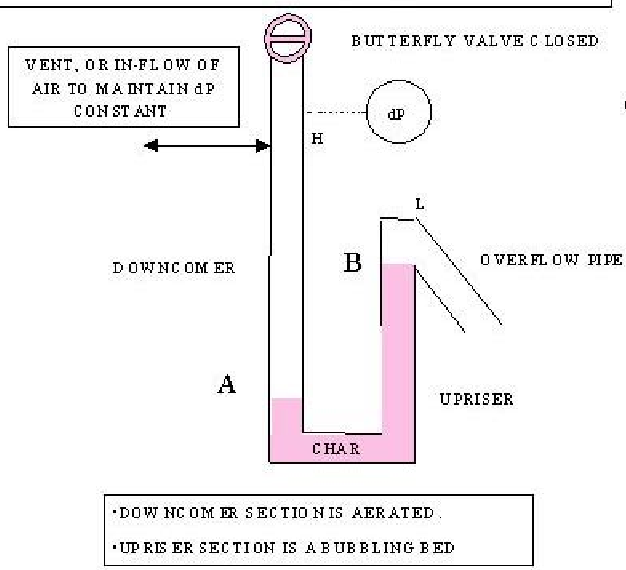
Pressure seal in Loopseal





- Approach:
  - Pressurized stand-leg (SP) of loopseal independently.
  - Varied Aeration to stand-leg, riser, H_o and P above stand-leg
- Observations:
  - ΔP_{lpsl} riser constant until v. high flows.
  - Height SP drops as ΔP_{lpsl} increased.
  - Aeration at SP base significant in determining ΔP's and H_{sp}

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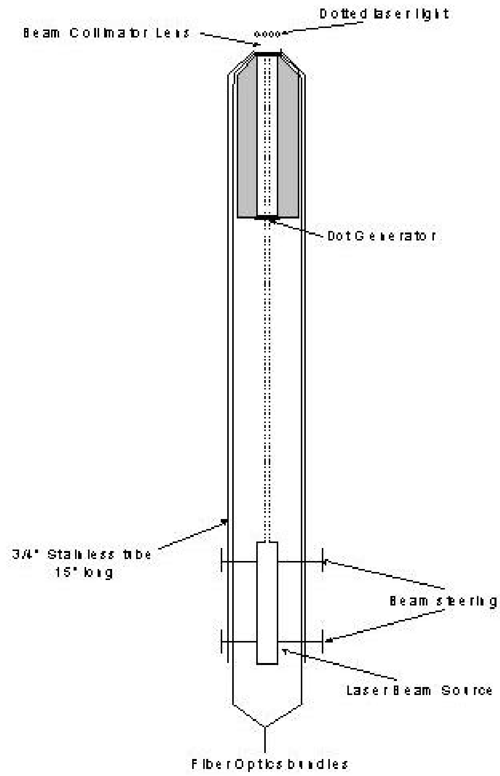
Solids Velocity Measurement Probe

- Dilute Phase Particle Velocity Measurement (Riser)
- Measures Both Direction and Speed of Particle
- Prototype Built and Tested
- Contract To Build Next Generation Probe Being Negotiated



Particle Velocity Measurement Probe

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